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# Red Lustrous Wheelmade ware: Analysis of organic residues in Late Bronze Age trade and storage vessels from the eastern Mediterranean

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ABSTRACT

Transport and storage vessels in Red Lustrous Wheelmade ware (RLWm ware) were traded across a large area of the eastern Mediterranean for approximately 300 years (*c.* 1500–1200 BCE) during the Late Bronze Age (*c.*1600–1000 BCE). The extreme consistency of the ceramic, in form, fabric, chemistry and mineralogy, points to a single production source for the ware, which, although no kiln sites have been identified, is generally accepted to have been on Cyprus. The aim of this study was to determine whether organic residues were present in this very fine, dense ware, and to characterise the contents of RLWm ware vessels from different sites, contexts and periods, and of different forms, to improve our understanding of the trade in this ceramic type. To that end, 101 RLWm ware sherds, together with three visible residues, were examined from sites in Turkey, Cyprus, Egypt and Syria. Residues were identified in more than half of the samples, indicating that organic material is absorbed into and preserved in this very fine fabric. Four commodities were identified: fat (probably plant oil), which in four residues was identified further as castor oil; beeswax; bitumen; and *Pinaceae* spp. resin. The commodities were found alone or, occasionally, one of the latter three was combined with the fat or oil. Fatty material was the only commodity present at all sites and its wide distribution may indicate that generally the vessels were used for a mixture or mixtures based on plant oils, in some cases containing castor oil. It was impossible to determine whether the beeswax, bitumen and resin formed part of this mixture or represented post-firing treatments of the ceramic to make it less porous. The identification of more than one type of residue indicates that RLWm ware vessels did not always contain the same commodity. No significant correlation could be detected between the vessel forms, and the dating of many of the sherds was not precise enough to reveal any variation through time. The type of residue present did vary depending on the geographical location of its final use. Beeswax was, with two exceptions, only present in samples from Turkey, while bitumen was found exclusively in samples from Cypriot sites. The occurrence of at least one example of every commodity in the samples from Cyprus is consistent with the theory that this ware was manufactured on Cyprus, and indicates that the vessels could also have been filled and exported from there. The variation in content of the vessels found in different geographical areas could highlight a special trading relationship between the Hittite heartland in Turkey and the Cypriot potters who produced the ware, and a possible trade in bitumen as a raw material between the north Syrian coastal area of Ugarit and Cyprus.

## 1. Introduction

This paper presents the results of organic residue analysis of one of the key storage and transport wares from the Late Bronze Age (LBA) (*c.* 1600–1000 BCE) of the eastern Mediterranean. It addresses questions about the contents of the vessels and provides insights into the trading relationships of Cyprus during the LBA.

Red Lustrous Wheelmade ware (RLWm ware) is a distinctive fabric in the eastern Mediterranean LBA ceramic assemblage. This very fine, dense fabric is well levigated, wheelmade and kiln fired at temperatures between 900° and 1000 °C (Artzy, 2001, 2007; Eriksson, 2001; Knappett, 2000; Knappett et al., 2005; Nordström and Bourriau, 1993; Serpico and White, 2000c). The fabric generally contains very few, small inclusions and few voids, although there are occasional examples in coarser variants, which differ only in the size and number of inclusions and voids, and a few examples containing silt; both these types of examples are mainly found at Turkish sites. Chemically, RLWm ware from sites across the eastern Mediterranean is extremely consistent (Knappett, 2000; Knappett et al., 2005; Schubert and Kozal, 2007). The pottery was self-slipped and burnished on the exterior before firing to

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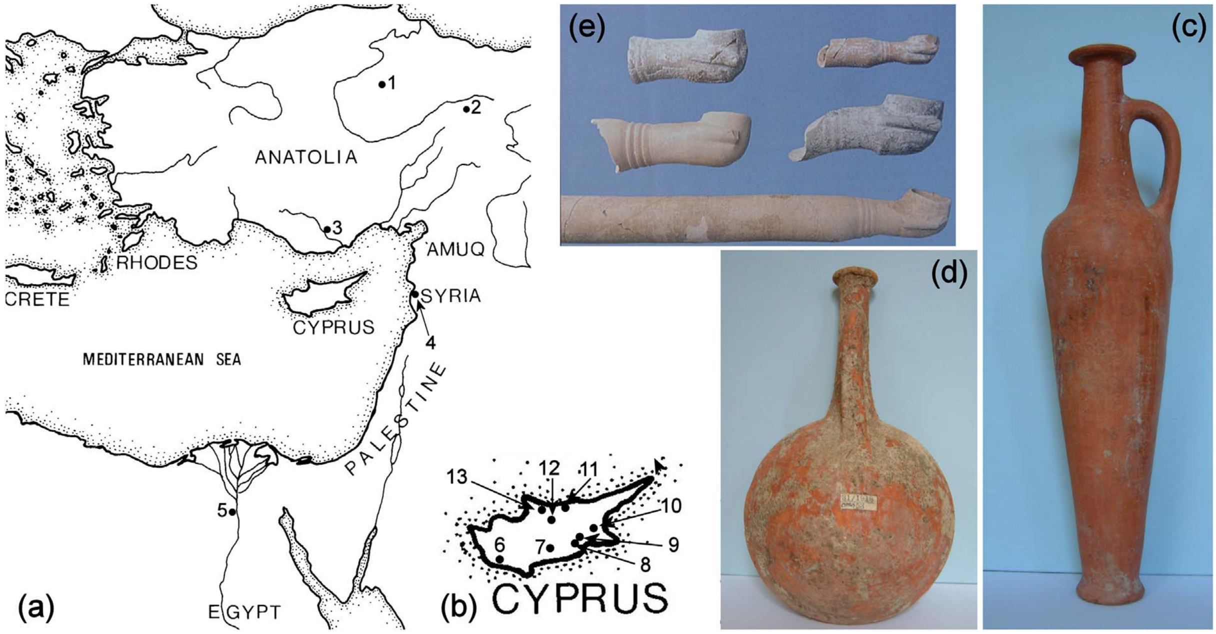


**Fig. 1.** (a) Map of the study sample sites in Turkey, Syria and Egypt: 1, Boğazköy, Turkey; 2, Kuşakli, Turkey; 3, Kilise Tepe, Turkey; 4, Tel Tweini, Syria; 5, Memphis Saqqara, Egypt. (b) Enlargement to show the study sample sites on Cyprus: 6, Kouklia; 7, Kalavassos-*Ayios Dimitrios*; 8, Arpera; 9, Hala Sultan Tekke; 10, Enkomi; 11, Kazaphani; 12, Dhenia; 13, Myrtou-Pigadhes). (c) A spindle bottle from Cyprus, (d) a lentoid flask from Cyprus, (e) arm-shaped vessels from Kilise Tepe. Map after Eriksson (1993, 2, Fig. 1, used with permission); photographs (c) and (d) © Val Steele; photograph (e) © Kilise Tepe Archaeological Project, used with permission.

give it its characteristic lustre, which is still visible on well preserved pieces (Eriksson, 1993; Knappett et al., 2005).

Transport or storage vessels in this fabric were produced between the 16th and 12th centuries BC. They are found in LBA contexts across a huge area of the eastern Mediterranean, from Hittite sites in central Turkey, through Jordan, Syria, Lebanon and Israel into Egypt, and on Cyprus, with a few pieces found further west on Rhodes and Crete (Eriksson, 1993; Knappett et al., 2005; Kozal, 2003, 2007; Mielke, 2007; Todd, 2001). Recent excavations have identified RLWm ware at Hittite sites in Turkey from the late 16th century BC, indicating that the greatest geographical range occurred around 1400 BCE (Eriksson, 1993; Grave et al., 2014; Manuelli, 2009; Mielke, 2007). After *c.*1400 BCE, RLWm ware disappears from Egypt and declines in Jordan, Lebanon, Syria and Israel. The distribution has been linked to the changing balance of power between Egypt and the Hittite Empire during this period (Eriksson, 1993), although this interpretation has been questioned with the latest discoveries of much earlier occurrences in Turkey (Grave et al., 2014; Manuelli, 2009; Mielke, 2007) and the identification of contemporary or earlier local ceramics in similar shapes at Turkish sites such as Mersin/Yumuktepe (Manuelli, 2009), Boğazköy, Kuşakli and Alaca Höyük (Mielke, 2007). The occurrence of the ware in relatively large amounts at LBA Hittite sites is particularly noteworthy, as RLWm ware is the only Cypriot ware imported by the Hittites in any quantity, and indeed the only foreign ware found on any significant scale at LBA Hittite sites. This possibly indicates a different kind of relationship between the area of production, probably northern Cyprus, and the Hittite Empire (Grave et al., 2014; Manuelli, 2009; Mielke, 2007).

RLWm ware is rare at most sites. Eriksson's (1993, 173ff) catalogue lists only 1173 securely provenanced examples. Even at the sites where it is considered abundant, it is often only present in very small amounts. For example, at Kalavassos on Cyprus, it forms only about 0.7% of the total LBA ceramic assemblage, less than imported Aegean (Mycenaean and a few Minoan) wares (1.8%) (South and Steel, 2007). At some sites it is extremely rare, for example at the site of Tell el-$^{c}$Ajjul in Gaza the 1999–2000 excavations yielded only 14 pieces of RLWm ware among a Cypriot ware assemblage of 830 pieces in total (Fischer, 2009). Many examples come from tomb or temple contexts and consist of complete or nearly complete vessels, which are not available for residue analysis. The rarity of the ware in general and the abundance of complete vessels among the extant examples have limited the amount of material available for analysis.

This rarity and the burial or cultic contexts of many of the samples have led to the conclusion that RLWm ware vessels were expensive, luxury items (Eriksson, 1993). However, despite the fine fabric and lustrous finish the ware is considered to be plain, functional and undecorated, especially when compared with the highly decorated wares being traded around the eastern Mediterranean from the Aegean. It therefore seems probable that the contents represented the valuable commodity rather than the vessels themselves (Donovan, 1993; Eriksson, 1993; Knappett et al., 2005; Mielke, 2007). The consistency of the fabric, in both chemistry and mineralogy, has led to the conclusion that it must have been manufactured in one area, possibly in one place, and maybe just one workshop. However, the location of this source of RLWm ware has remained a mystery since its first classification in the late 19th century: wherever it has been found it has been classed as imported (Eriksson, 1993; Knappett, 2000; Knappett et al., 2005; Nordström and Bourriau, 1993). Studies of the distribution of the ware and elemental and thin section analysis of the fabric have suggested northern Cyprus as a source, although no kiln sites have been found (Eriksson, 1993; Knappett, 2000; Knappett et al., 2005). Recent research has identified an area in south-western Cyprus as the source, although this was based on elemental analysis of the ware and the suggested area does not match the mineralogy of RLWm ware samples in thin section (Grave et al., 2014).

There are three main forms of RLWm ware vessels: spindle bottles; lentoid or pilgrim flasks; and arm-shaped vessels, in which a tapering cylinder forms the container, with an opening into a cup held in a more or less stylised representation of a right hand (Fig. 1) (Eriksson, 1993; Knappett, 2000; Mielke, 2007). The spindle bottle is the most common form, manufactured throughout the lifetime of the ware, and forms the majority of examples found in Egypt (Eriksson, 1993; Merrillees, 1968; Nordström and Bourriau, 1993). While the first two forms are ideally suited to transport or storage, the exact function of the arm-shaped vessels has never been established. They show no signs of burning within or outside the 'cups', so are not comparable with similarly shaped LBA Egyptian incense burners. Suggested theories have ranged from libation pouring or a non-religious ritual to a LBA form of branding, where the shape of the vessel indicated the contents in a largely illiterate society (Eriksson, 1993; Mielke, 2007). Mielke (2007) has suggested that the occurrence of spindle bottles and arm-shaped vessels at Hittite sites indicates a linked usage, with the spindle bottles being used to transport a liquid product and the arm-shaped vessels being used to dispense the same product during a ritual such as the anointing of people or statues. There is a difference in the distribution of the different forms, with arm-shaped vessels and spindle bottles dominating at Hittite sites in Turkey and spindle bottles comprising almost all the finds from Egypt and the Levant, while examples of all shapes, including rare shapes that are not arm-shaped vessels, spindle bottles or lentoid flasks, are found on Cyprus (Eriksson, 1993).

In addition to canonical RLWm ware, there are also vessels circulating in the LBA eastern Mediterranean in the same or very similar shapes to RLWm ware but made from different fabrics (Artzy, 2007; Bergoffen, 2013; Knappett and Kilikoglou, 2007; Manuelli, 2009; Merrillees, 2007; Mielke, 2007). Some of these 'variants' or 'imitations' were made in fabrics local to the areas where they are found (Bergoffen, 2013; Knappett et al., 2005; Manuelli, 2009; South and Steel, 2007) but scientific analysis of the fabrics has shown that some were probably also imported from Cyprus (Bergoffen, 2013). Eriksson (1993) devotes a complete section of her catalogue to these examples. Some are very good imitations, almost indistinguishable from canonical RLWm ware without petrographic and/or chemical analysis (Bergoffen, 2013), while some are clearly not intended to be the same. The latter are found in a range of fabrics, often local to the find site, and are variable in quality (Bergoffen, 2013; Mielke, 2007). Bergoffen (2013) made the interesting observation that the distribution of these variants or imitations is exactly the same as RLWm wares, both in time and space, sometimes both occurring in the same excavation context. In particular, arm-shaped vessels and spindle bottles in non-RLWm ware fabrics are found across the Hittite sites in Turkey at the same time as, and possibly before, the occurrence of RLWm ware at these sites (Manuelli, 2009; Mielke, 2007). This would make the terms imitation or copy for these wares incorrect as they are entirely contemporary and used in addition to, rather than instead of, RLWm ware vessels (Bergoffen, 2013). Some authors have suggested that arm-shaped vessels and spindle bottles may be derived from or a development of shapes already in use in Hittite controlled areas of Turkey (Manuelli, 2009; Mielke, 2007). On the other hand, Merrillees (1968) saw spindle bottles as a development of an early shape of Base Ring ware, another LBA ware known to have been manufactured on Cyprus.

Since the identification of RLWm ware as a distinct ware in the 1890s, there has been much speculation and several theories regarding the contents of the vessels. The contents are particularly important if this ware is considered to be only a container for a commodity or commodities being traded and used across the eastern Mediterranean. Merrillees (1968) suggested that spindle bottles "contained a fluid substance which never varied and could have been poured out through the tall narrow necks of the vessels". From the rarity of the ware and its occurrence predominantly in tomb or temple contexts, it has been assumed that the contents were a 'value-added' commodity, such as scented oil, medicine, flavouring or fine wine, rather than one of the bulk staples of eastern Mediterranean trade during the LBA, such as olive oil or resin (Eriksson, 1993).

An early mention of the contents of spindle bottles is made by Schaeffer (1949). He describes a spindle bottle from Ras Shamra as containing a resinous deposit (Schaeffer, 1949). Observations made by Merrillees (1968) on the contents of two complete vessels that may be RLWm ware from a tomb at Deir el-Medina, Egypt, mention a "brown, viscous, oily liquid" and "a greasy liquid". He also mentions chemical analysis, using wet chemistry techniques, of two spindle bottles and reports "fat" or "stearin" (one of the components of fats) along with various other materials including ferric iron, sodium carbonate and sand. Analysis by wet chemistry of the contents of a vessel from the Medelhavsmuseet (analysed further during this study) by two separate analysts suggested a reducing sugar or honey as the contents, although the second analyst admitted that the presence of honey was conjecture (Åström, 1969). A reference made by Eriksson (1993, 143) to the gas chromatography–mass spectrometry (GC–MS) analysis of the contents from an Egyptian spindle bottle, which identified palmitic ($C_{16:0}$) and stearic ($C_{18:0}$) acids as the main components, cannot be verified (Cariveau et al., 1986; Eriksson, 1993). Analysis of the contents of a spindle bottle in the Royal Ontario Museum (Toronto, Canada) by McGovern et al. (1997) using Fourier transform–infrared spectroscopy (FT-IR) and high-performance liquid chromatography (HPLC), identified resin and wine (this residue was also re-analysed during this study). None of these studies provided an overall insight into the contents of RLWm ware vessels but did provide a possible range of commodities to be considered.

Preliminary results from the current study were reported in Knappett et al. (2005). This paper extends the results reported in Knappett et al. (2005) considerably, doubling the number of samples and increasing the number of sites from seven to 13. The increase in number of sites and geographical areas covered, together with further biomolecular and compound-specific stable isotopic analysis of some of the samples, has provided a much clearer overall picture of the ware and its contents. Two new materials (pine resin and castor oil) have been identified and the results of isotopic analysis have supported the identification of plant oil(s). Further analysis by HPLC with tandem mass spectrometry (HPLC-MS-MS) was also carried out on selected residues. This work has provided a much clearer picture of the contents of RLWm ware vessels that was not possible using the preliminary results. Identifying the contents of RLWm ware vessels could potentially answer some of the outstanding questions concerning the use and trade of these containers across the LBA eastern Mediterranean. For example, were the vessels all used for the same commodity or did the different forms relate to different contents designed for a largely illiterate customer base? Were vessels going to different destinations filled with different commodities, in an example of ancient niche marketing? Or were the containers filled or reused locally in the areas to which they were traded? Are the contents of 'imitation' vessels the same as canonical RLWm ware vessels and do any differences or similarities provide further information about the relationship between the two types and their trade? Does the trade in RLWm ware provide any insights into trading and other relationships between the major political powers of the LBA eastern Mediterranean?

The aims of this study were to establish whether residues had been absorbed and survived in this very fine pottery fabric and its imitations, to identify those residues and to determine whether residues varied with the form of the vessel, through time, with context of the finds or with the final destination of that vessel. A final aim was to determine whether the results provide further insights into the political and trading relationships of the LBA eastern Mediterranean.

## 2. Materials and methods

On the basis of the results of previous analyses of the contents of RLWm ware vessels (fatty material, resin, sugars/fruit, honey; see above), GC–MS analysis was considered to be an appropriate analytical tool for this project, as it is ideally suited for the analysis and identification of fats and resins and has been the accepted first step in the analysis of ceramic residues since the early 1990s (Evershed, 1993, 2008b; Evershed et al., 1990). Although sugars rarely survive in the archaeological record, they have been identified in archaeological residues and in modern soils using standard sample preparation and GC–MS methods (Bleton et al., 1996; Bonaduce et al., 2007; Colombini and Modugno, 2009; Medeiros and Simoneit, 2007; Simoneit et al., 2004). The detection of wine in archaeological residues is a contentious subject (Evershed, 2008b; Steele, 2013; Stern et al., 2008b). At present, the most generally accepted biomarkers for wine residues are tartaric acid (present in all wine) and syringic acid (present only in red wine), although the presence of these acids does not provide any information about whether fermentation has occurred (Barnard et al., 2011; Guasch-Jané et al., 2004, 2006; Pecci et al., 2013; Stern et al., 2008b). As wine, or a wine-based product, has been suggested as a possible commodity traded in RLWm ware vessels, the analysis of a limited number of RLWm ware sherds by HPLC-MS-MS was also carried out to determine whether there was any evidence for the presence of wine. In this case only tartaric acid was targeted, as a general identification of wine was the main aim of the analysis rather than distinguishing between red and white.

The possibility that the contents of RLWm ware vessels were value-added commodities was also taken into consideration, in particular the theory that these vessels always contained a perfumed oil (or more correctly a scented oil) (Eriksson, 1993; Mielke, 2007). The high-value liquid commodities of the LBA eastern Mediterranean were fine wines, medicinal mixtures and scented oils (Knapp, 1991), and there is textual and archaeological evidence of production and trade in scented preparations across the Aegean and the eastern Mediterranean during this period (Bergoffen, 1991; Knapp, 1991; Manniche, 1999; Palmer, 2003; Shelmerdine, 1985). In the LBA, before the discovery of distillation techniques, perfumes were produced by steeping the scented ingredients in oil, fat, wine, honey, fruit paste or water (Manniche, 1999; Shelmerdine, 1985). The compounds from many scented ingredients are very volatile and unlikely to survive over archaeological time, but a range of carriers for those ingredients (fat or oil, wine and honey) may survive and be detected by GC–MS analysis. The parallels between these possible ingredients and the results of the previous analyses of RLWm ware residues further supported the decisions made about appropriate analytical methods.

Having identified fatty material in many of the samples, the next question was whether this fatty material could be characterised further. Compound-specific stable isotopic analysis of animal fats has become routine for establishing the nature of terrestrial and aquatic fats from archaeological residues (Copley et al., 2005a, 2005b, 2005c, 2005d; Craig et al., 2011; Dudd and Evershed, 1998; Evershed, 2008a, 2009; Heron et al., 2010, 2013) and is based on the differences in carbon (or sometimes hydrogen) isotopic fractionation produced by the different metabolic pathways employed by different species in the production of fatty acids or other compounds.

The shape of RLWm ware vessels, all of which have very narrow neck openings and, in the case of spindle bottles and arm-shaped vessels, long narrow bodies, makes the use of animal fats in any large quantities unlikely, as only something liquid at room temperature could ever be extracted from any of these shapes without significant heating (for which there is no evidence). For example, pure olive oil (used extensively in the LBA eastern Mediterranean) starts to solidify at about 3 °C (Gunstone, 2004) whereas most animal fats are solid at ambient indoor temperatures in temperate regions (15–25 °C). The addition of any quantity of animal fat to olive oil would raise the melting point and risk solidifying the contents of the vessels, particularly in regions such as central Turkey where the average winter temperature is $-2$ °C (Turkish State Meteorological Service, 2006). This leads to the conclusion that any fatty material present in the vessels probably consisted largely of plant oils. Although many of the residues were high in unsaturated fatty acids and their degradation products, this is not a definitive identification of the presence of plant oils. Analysis of bulk carbon isotopic signatures has been used since 1985 to distinguish $C_3$ and $C_4$ plants, as the different metabolic pathways of the two types of plants produce different fractionation of carbon isotopes and result in different isotopic signatures within the plant tissue (Hastorf and DeNiro, 1985). The analysis of the carbon isotopic signatures of individual fatty acids has been used on modern oils to determine whether an oil has been adulterated (Spangenberg, 2016; Spangenberg et al., 1998; Spangenberg and Ogrinc, 2001; Woodbury et al., 1998a, 1998b). It has also been used on archaeological material to detect plant oils (Copley et al., 2005d; Spangenberg et al., 2006), although in Copley et al. (2005d) no modern vegetable oils were analysed for comparison and the archaeological material was considered to be ruminant animal fat.

The results of previous work show that plant fatty acids have isotopic signatures that overlap, at least to some extent, with those from animal fats (Copley et al., 2005d; Spangenberg et al., 2006). To advance this field of study and to examine the origin of the RLWm ware fats, eight modern plant oils from Mediterranean sources were analysed by gas chromatography–combustion–isotope ratio mass spectrometry (GC-C-IRMS) to create a comparison for the archaeological material available for analysis. The analysis of this modern material, together with one of the archaeological samples and the rationale and reasoning behind the analysis, has already been published (Steele et al., 2010). In addition to the modern plant oils, as some of the sherds yielded residues containing both beeswax and fatty material, it was considered prudent to examine how palmitic acid ($C_{16:0}$) originating from beeswax might affect the isotopic signature of $C_{16:0}$ originating from an oil or fat. Beeswax is a highly variable material and yields very little stearic acid ($C_{18:0}$); indeed, the main effect of beeswax on the isotopic signature of mixed samples should be seen in $\delta^{13}C_{16:0}$ because the amount of $C_{18:0}$ is so low. Attempts have been made to measure $\delta^{13}C_{16:0}$ from beeswax (Evershed et al., 1997), although when investigating the isotopic composition the alkanes are usually the target (Evershed et al., 2003, 1997). In this case the effect on $\delta^{13}C_{16:0}$ was the main concern, so the isotopic signatures of the same two fatty acids measured in the plant oils and the archaeological samples were also measured in beeswax. Having established some modern results for plant oils and beeswax, selected samples of the residues were also sent for GC-C-IRMS analysis to determine whether the isotopic signatures of the residues yielded further information about their origin.

To study the commodities stored or traded in RLWm ware vessels, 101 sherds from 13 sites in Turkey, Cyprus, Syria and Egypt, and three visible residues from Egypt and Cyprus, were analysed using gas chromatography (GC) and GC–MS. Given the rarity of the ware and the impossibility of sampling a significant amount of the extant material, 101 sherds were considered to provide a reasonable number for the study. Although some sites are only represented by one sherd (see below), the aim was to investigate the ware as a whole, not its use at individual sites, so these individual samples were included to contribute to the overall picture of the ware contents.

In addition to the RLWm ware sherds, 13 sherds of local pottery from four LBA sites (Boğazköy and Kuşakli in Turkey, Kazaphani and Kalavassos from Cyprus) were examined for comparison. These were either vessels of the same forms in local fabric or what appeared to be imitations of RLWm ware in local fabrics. As outlined above, these may have been used not as replacements for, but in addition to, RLWm ware vessels, and any differences or similarities in the contents of these non-RLWm ware vessels may help determine how they related to the canonical ware.

The sherds (101) studied came from eight LBA sites on Cyprus, Arpera (10), Dhenia (1), Enkomi (2), Hala Sultan Tekke (13), Kalavassos (9 RLWm ware), Kazaphani (9 RLWm ware), Kouklia (5) and Myrtou-Pigadhes (1); three sites in Turkey, Boğazköy (31 RLWm ware, 10 local), Kilise Tepe (12) and Kuşakli (3 RLWm ware, 1 local); one site in Syria, Tel Tweini (Gibala) (1); and one site in Egypt, Saqqara (4). Nine samples for compound-specific stable isotope analysis were selected on the basis of the amount of available sherd material and the abundance of the residue as determined by GC and GC–MS, as a minimum amount of lipid is required for this analysis to produce reliable results. These comprised four samples from Boğazköy (sherds 1, 21, 28 and 29), two from Kilise Tepe (sherds 205 and 206) and one each from Kouklia (sherd 6) and Saqqara (sherd 2). Five of these samples were considered to be representative of the fatty material alone (Boğazköy sherd 21, both Kilise Tepe samples and those from Kouklia and Saqqara). Two of the sherds from Boğazköy (28 and 29) were considered to be mixtures of beeswax and fat, while the sample from Boğazköy sherd 1 was actually taken from the wrong surface of the sherd in error and was probably mostly contamination. The 17 samples for HPLC-MS-MS were selected on the basis of availability, as they required a separate sample to be prepared and many of the sherds were too small for two samples to be taken. The samples included a mixture of six sherds that had been identified as containing archaeological materials using GC–MS (Boğazköy sherds 10 and 17, Kazaphani sherd 2, Kouklia sherd 1 and Kilise Tepe sherds 204 and 5501) and 11 that had not yielded archaeological residues (Boğazköy sherds 2, 6, 9, 15, 18, 20 and 27, Kazaphani sherd 1 and Kilise Tepe sherds 43, 201 and 203).

All sherds were dated to the LBA, although some came from contexts that did not have a secure date within that period. Some had been stored for many years in museum collections while others had been recently excavated. It was not always possible to determine how the sherds had been treated prior to analysis. The sherds from Boğazköy were acquired directly from the site without washing, while the sherds from Kuşakli had been washed in acid, but in many cases there was no information about the treatment of sherds that had been stored in museums.

Three visible residues were also analysed by GC–MS and GC-C-IRMS, one from Saqqara, Egypt, and two from museum collections that could only be provenanced generally to Egypt and Cyprus. However, as the latter two samples were very clearly the contents of spindle bottles it was felt that, despite lack of a definite provenance, they should be analysed. The visible residue from Saqqara was also analysed by HPLC-MS-MS to determine whether it contained tartaric acid. Full details of the sources of the sherds, visible residues and relevant publications can be found in Table 1 in the Supplementary data.

The plant oils used as reference materials for comparison with the archaeological residues, with one exception, included oils from plants for which there is evidence of use in the LBA eastern Mediterranean, namely olive oil (three samples), almond oil, moringa oil, sesame oil and walnut oil. The exception was argan oil, for which there is no evidence of use in the LBA but it is an oil of Mediterranean origin from a $C_3$ plant (Steele et al., 2010). For the beeswax samples, in an attempt to avoid wax that had been bleached, heat treated or adulterated with paraffin wax, two samples of wax were taken from commercial honeycomb. One sample was obtained from Honeycomb chunk comb honey (packed by Honeycomb Co. Ltd., Lancaster, UK) produced in Hungary and purchased in a glass jar. The second sample was obtained from Borage Herbal Comb Honey (Bee Health Manufacturing, Bridlington, East Yorkshire, UK), purchased in a plastic box.

To avoid introducing contamination during sample preparation and analysis, high-purity solvents were used, tools and glassware were triple-washed in solvent, and nitrile gloves were worn at all times. Method blanks were run with each batch of samples to check for contamination introduced in the laboratory.

Samples were removed from both surfaces of each sherd using a modelling drill (Dremel) with a tungsten carbide bit to a depth of *c.* 2 mm. Interior and exterior surfaces were sampled separately to check for possible contamination from the burial environment and handling. Contamination from burial or post-excavation treatment or handling is likely to appear on both sides of a sherd, while residues of archaeological origin will be predominantly on one surface, usually the interior, of the ceramic. Sampling without first removing the outermost layer of ceramic is an accepted method of sampling archaeological sherds for residue analysis and has been used extensively in high-profile projects (Craig et al., 2007, 2011; Heron et al., 2013, 2015). It also allows the maximum amount of archaeological residue to be extracted as this is mostly present in the outer 2 mm of sherd (Stern et al., 2000). There is no published evidence that removing the outermost layer of the ceramic removes all, or even most, of the contamination, particularly plastic additives, many of which are extremely volatile and will migrate at least as far, possibly further, into the ceramic as materials from the original use of the vessel. Visible residues were sampled by removing a small portion using a clean scalpel. Approximately 0.1 g of sherd powder, or 5–10 mg of visible residues, was accurately weighed and extracted with three 1 ml aliquots dichloromethane/methanol (2:1 v/v). Some extracts were saponified by heating with 3 ml 0.5 M sodium hydroxide at 70 °C for 2 h, and neutral and acidic fractions extracted with hexane.

Modern beeswax samples were separated from honey by carefully removing a small sample of the comb using a scalpel, removing as little honey as possible. The samples were allowed to drain on a clean watch glass and then heated to 60 °C, causing the wax to melt and rise to the surface of the samples. The waxes were skimmed off the surface and prepared as for the archaeological samples.

Prior to analysis by GC or GC–MS, the samples were trimethylsilylated with *N*,*O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA) with 1% trichloromethylsilane (TMCS). A measured amount of $C_{34}$ *n*-alkane standard was added before analysis to allow quantification.

Larger samples (0.2–0.5 g sherd powder, 10 mg visible residue) were taken for compound-specific carbon stable isotope analysis by GC-C-IRMS. These were extracted and saponified as described above, then methylated by heating with 14% boron trifluoride methanol complex for 1 h at 70 °C. The reaction was quenched with a few drops of deionised water, and after cooling the residues were extracted with three 2 ml aliquots of hexane.

For HPLC-MS-MS, the method used for extraction and analysis was based on that of Guasch-Jané et al. (2004). Extraction was carried out on the sherd powder or visible residue by sonicating with 0.1% formic acid in methanol:water (20:80 v/v), followed by centrifugation and pipetting off the supernatant. The extract was reduced in volume to about 20% of the original under a stream of dry nitrogen with gentle heating (40 °C) and stored in a refrigerator until analysis.

GC analysis was carried out on an Agilent 6890 gas chromatograph fitted with a split/splitless injector (split ratio 1:5) and a flame ionisation detector (FID). The injector was maintained at 300 °C and FID at 350 °C with a hydrogen flow of 30 ml/min and an air flow of 400 ml/min. Several columns were used during the study, all non-polar 100% dimethylpolysiloxane or slightly polar 5% diphenyl, 95% dimethylpolysiloxane. All are similar in their chromatographic performance, the main difference being in altered retention times. The oven temperature programme was isothermal at 50 °C for 2 min, 50°–340 °C at 10°/min, isothermal for 10 min. GC–MS analysis was performed on an Agilent 5890 Series II GC connected to an Agilent 5972 mass spectrometer. The splitless injector and interface were maintained at 340 °C with helium carrier gas and the columns and oven temperature programming were identical to those used for GC analysis. Because of a catastrophic equipment failure, some of the samples were analysed at the Department for Conservation and Scientific Research at the British Museum (London, UK). Here analysis was carried out on an Agilent 6890 GC connected to an Agilent 5973 mass selective detector. Injection was splitless with the injector at 250 °C. The carrier gas was helium at a constant flow through an Agilent 30 m × 0.25 mm × 0.25 μm HP5-ms column. Oven temperature was 2 min isothermal at 50 °C rising at 10°/min to 325 °C with a 10 min isothermal hold. In all cases the column was inserted directly into the mass spectrometer where electron impact ionisation (EI) occurred at 70 eV. Mass spectra were collected by scanning over the range *m/z* 50–700.

Compounds were identified by comparison with the NIST library (NBS75K) of mass spectral data, published data and standard materials. Peak area measurements for quantification were carried out using the interactive RTE integrator within the Agilent Chemstation enhanced data analysis software. Abundances were calculated as micrograms (μg) of compound per gram of sherd.

Bulk stable isotope analysis of visible residues was carried out on two samples of bitumen extracted from one sherd. Carbon isotopic values for samples were acquired on a Finnegan Delta Plus XL isotope ratio mass spectrometer; δD values of samples were acquired on a Europa Scientific Geo 20–10. Standards of known isotopic signatures were used as controls to check the accuracy of the results.

GC-C-IRMS was carried out at two different external laboratories using standard methods (Heron et al., 2013; Steele et al., 2010). Duplicate analyses were run on each sample and the results averaged. Instrument performance was regularly checked by running a standard containing fatty acid methyl esters of known isotopic composition. Samples were corrected for the addition of modern carbon during the derivatisation process using a standard mass balance equation (Copley et al., 2005a; Jones et al., 1991; Woodbury et al., 1998b) and modern samples were corrected for post-industrial change in isotopic signature of atmospheric carbon (Dudd and Evershed, 1998; Steele et al., 2010).

HPLC-MS-MS was carried out on a Waters Alliance 2695 HPLC fitted with a Phenomenex Synergi 4u fusion-RP 80-A column, operating in reverse phase at a pressure of 63–73 bar. The HPLC was operated at a flow rate of 0.2 ml/min and the mobile phase was programmed from 100% 0.1% formic acid in water to 100% acetonitrile in phases. This was connected to a Micromass Quatro Ultima triple quad mass spectrometer. Conditions were optimised by repeated injections of a standard solution, the optimum conditions for electrospray ionisation (–ve) being capillary voltage 2.44–2.52 kV, collision energy 15 V, source temperature 100 °C, desolvation temperature 360 °C and cone voltage 99 V. The mass spectrometer was set up to scan for the pseudo-molecular ion of tartaric acid ($[M–1]^+$ at $m/z$ 149) and stable daughter ion ($m/z$ 87). The limit of detection, determined by running increasingly dilute standard solutions of tartaric acid, was determined to be 0.01 μg/ml.

In addition to the analysis of the residues, some investigation was carried out into the capacity of RLWm ware vessels, as this is integral to the idea these vessels were not used to store and transport bulk commodities but one or more high-value products. There has only been one published study recording measurement of the volume of different forms of RLWm ware vessels (South and Steel, 2007). To get an approximate idea of the capacity of these vessels, estimations of the range of volumes were made using scale drawings available for extant examples employing methods outlined by Ericson and Stickel (1973), Råde and Westergren (1988), Senior and Birnie (1995) and Rice (2005). These involve approximating the shape of a vessel using a series of geometric shapes and calculating the volume enclosed by those shapes using the appropriate mathematical formulas, taking into account the thickness of the vessel walls. Scale drawings are used to determine the actual dimensions of each vessel to be used in calculations. In this case a spindle bottle was approximated by a conical frustum topped with an inverted spherical section, a lentoid flask as two spherical sections, and an arm-shaped vessel as a conical frustum. Volumes were calculated for six spindle bottles, two lentoid flasks and three arm-shaped vessels. This method does not produce an exact volume because the shape of each vessel has been idealised. However, it does provide a rough estimate of the volume and will distinguish between volumes of several litres and volumes of tens of millilitres. The scale drawings used to estimate vessel volumes were from Eriksson (1993) and South and Steel (2007). Only drawings specifically designated as accurate scale drawings, with information about the scaling used and/or a record of the original measurements, were included in the exercise. An attempt was made when choosing the vessels to ensure that extreme sizes, both very small and very large, were included, to give an idea of the range of volume available for each vessel form.

## 3. Results and discussion

A full summary of the results is given in Table 2 in Supplementary data. Sixty-one of the 101 RLWm ware sherds and 11 of the 13 local sherds contained organic residues of archaeological significance; five of the RLWm ware samples from one site (Hala Sultan Tekke) produced results too poor to use because of equipment failure combined with a limited capacity to rerun samples at the British Museum. Overall this meant that residues were preserved in *c*. 60% of RLWm ware vessels. The most abundant residues were present in the sherds from Saqqara and were present at abundances of up to 1.7 mg/g of sherd. For comparison, Evershed (2008a) reported that the most abundant archaeological residue discovered by his research group was present at 17.8 mg/g, although the mean abundance from all research up to 2008 was much lower at 0.1 mg/g. Experimental meat boiling in replica pots produced a maximum absorption of 21.8 mg/g, while soaking sherds in olive oil resulted in an up-take of 13.5 mg/g. Ethnographic cooking pots used for 40 years have only yielded residues of 5.4 mg/g (Evershed, 2008a). Most of the RLWm ware sherds yielded less lipid than the 1.7 mg/g from Saqqara. Thirty-two residues were quantified and the yields ranged from 0.016 mg/g to 1.7 mg/g, with about 15% being above 0.1 mg/g and the average concentration being 0.139 mg/g. These results clearly demonstrated that this fine, dense ceramic fabric has the capacity to absorb and preserve organic material.

Preservation was not the same at every site, for example out of nine RLWm ware sherds from Kalavassos only four (44%) yielded residues of archaeological significance, while at Boğazköy 70% (21 out of 30) yielded residues. The pottery from Kalavassos was in a poor state of preservation, with many sherds being flaky and some reduced to powder, which may explain the very poor preservation of residues from that site.

No difference could be detected in levels of preservation between sherds that had been stored in museums and those that had come from recent excavations. The most striking difference between museum samples and recently excavated material was the degree of contamination with modern plastics and fingerprint lipids. Plastic contamination is usually identified by the presence of phthalates, modern synthetic compounds, with no equivalent in the ancient world, used as plasticizers. These may be accompanied by compounds such as alkylamides (oleamide, erucamide and docosamide) used as slip agents. There are potentially hundreds of different plastic additives added to plastics singly, or occasionally in pairs, as slip agents, ultra-violet (UV) stabilisers, plasticizers and fillers (Bradley and Coulier, 2007; Zweifel et al., 2009). However, most of these are recognizable as modern materials as they rarely or never occur in nature, or are present in small abundances unlikely to add significantly to a ceramic residue. The presence of phthalates and other plastic additives is the result of storage in plastic bags or boxes or close proximity to expanded plastic foams. Fingerprint lipids consist mainly of amino acids, fatty acids, acylglycerols, wax esters, squalene and cholesterol (Archer et al., 2005; Cadd et al., 2015). Squalene degrades relatively quickly and contamination from modern handling is recognised by the presence of large concentrations of squalene and cholesterol in the residues on one or both surfaces (Evershed, 1993). Fatty material from sherds yielding significant levels of squalene and cholesterol were excluded as archaeological residues because of the impossibility of distinguishing archaeological material from human skin lipids. It should also be noted that squalene occurs naturally in relatively high concentrations in some plant oils (being most abundant in olive oil) and in the liver oils of some aquatic species (Gunstone, 2004; Padley et al., 1994), but its sensitivity to degradation largely rules out these sources in archaeological samples. In many sherds there were no biomarkers for contamination at all or only traces of phthalates.

Having dismissed as possible contamination all the fatty residues yielding both squalene and cholesterol, the remaining residues were examined carefully to determine which could be considered residues of archaeological interest, and which consisted predominantly of modern contamination. All residues present at $< 10$ μg/g were dismissed as background based on previous research (Evershed, 2008a; Stern et al., 2000). In the remaining residues the interior and exterior residues were compared and, if compounds were present on both sides of the ceramic at similar concentrations, these residues were dismissed as

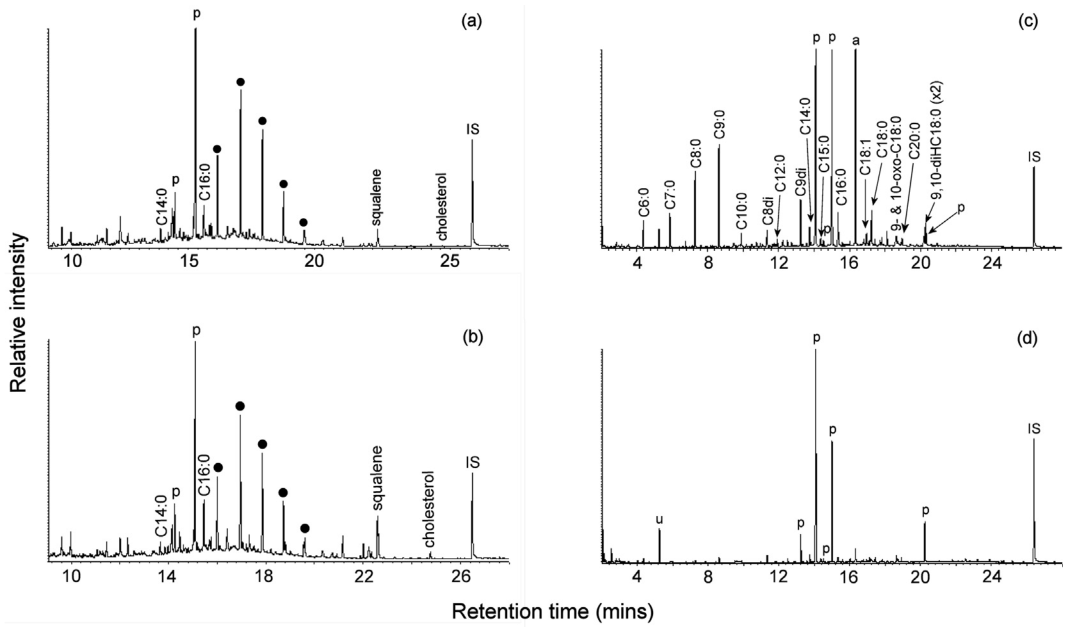


**Fig. 2.** Myrtou-Pigadhes sherd 1 (a) interior and (b) exterior residues showing similar residues on each surface. This residue was dismissed as contamination. Kalavassos sherd 8 (c) interior and (d) exterior residues showing plastic contamination on both surfaces but a fatty residue on the interior only. *x*, number of carbon atoms in molecule, $C_{x:y}$, fatty acid with *x* carbon atoms and *y* double bonds; C*x*di, diacid; *y*,*z*-diHC*x*, dihydroxy fatty acid, hydroxyl groups at carbon *y* and *z*; *y*-oxo-C*x*, oxo-fatty acid, oxo group at carbon *y*; IS, internal standard; p, phthalate plasticizer; a, artefact of the machine; u, unidentified compound.

contamination (see above). Compounds that were only present in significant abundances on one surface of a sherd were considered to represent residues of archaeological significance, particularly where they constituted a range of compounds specific to one natural material. This is illustrated in Fig. 2.

Four main commodities were identified in RLWm ware and local sherds. These were fat or oil, beeswax, bitumen and *Pinacea* spp. resin, sometimes occurring alone and sometimes in mixed residues. The mixed residues always consisted of fat or oil with one of the other three materials.

### 3.1. Fatty material

Twenty-two of the RLWm ware sherds and all three visible residues yielded a mixture of fatty acids dominated by $C_{16:0}$ and $C_{18:0}$, which is typical of degraded fats and oils (Evershed, 1993, 2008b; Heron and Evershed, 1993) (Fig. 3 and Table 2). Twenty of these contained the unsaturated $C_{18:1}$ fatty acid, in 19 of these cases in greater abundance than $C_{18:0}$. Plant oils and aquatic fats are particularly rich in unsaturated fatty acids, but these samples lacked the longer chain fatty acids present in aquatic fats, indicating an oil of vegetable origin. This was supported by the presence in 16 absorbed and all visible residues of significant abundances of short-chain fatty acids, in the range of $C_{6:0}$–$C_{11:0}$ and with a maximum at $C_{9:0}$. In seven of these 19 residues, diacids with the same range and distribution as the short-chain fatty acids were also present. Short-chain and dicarboxylic fatty acids are regarded as the degradation products of $C_{18:1}$ isomers (Copley et al., 2005d; Evershed, 2008a). In 13 absorbed and the three visible residues, ranges of hydroxy-, dihydroxy- and oxo-fatty acids were also identified (Fig. 3), which are also considered indicative of degraded, unsaturated fats (Copley et al., 2005d; Evershed, 2008a; Gülaçar et al., 1990; Regert et al., 1998). In general, where $C_{18:1}$ was present in high abundance, the residue yielded a suite of compounds typical of a degraded unsaturated fat (Copley et al., 2005d; Regert et al., 1998). In one absorbed residue (Kalavassos 8) and all three visible residues a low abundance of ricinoleic acid, the biomarker for castor oil (Copley et al., 2005d; Gunstone, 2004), was identified (Fig. 3). Its survival in these residues indicates the presence of at least some castor oil in the original fatty material. It is possible that castor oil may have formed a significant proportion of the commodity, as ricinoleic acid is very vulnerable to degradation and rarely survives in archaeological residues. In the light of the shape of the vessels, which all have very narrow necks, it would seem that any commodity stored or traded in them would need to be liquid at room temperature, supporting the identification of the fatty material as a plant oil rather than an animal fat.

In 15 cases fatty acid residues were present only on the interior surfaces of vessels; six sherds yielded residues only from the exterior surfaces, and one had residues on both surfaces. The interior residues probably represented the contents of the vessels, either from their original use or from subsequent reuse. There are a number of possible explanations for the residues being present only on the exterior surfaces. They could represent exterior coatings or decoration but, in the case of fatty material, exterior decoration seems unlikely. Some kind of exterior coating is a possibility, but the burnished nature of the ceramic makes an extra coating on the outside surfaces of the vessels less probable as it would not add anything to the already burnished surface. A third possibility is that exterior residues were formed by the liquid commodity dripping down the exterior during filling or dispensing of the contents. In the one case where residues were present on both surfaces this seems a feasible explanation, but in cases where no interior residue survives it is harder to envisage a reasonable scenario that would produce this result. It is possible that the dismissal of residues because of possible contamination has actually eliminated some archaeological material from the interior surfaces of these vessels.

Fatty material was present in at least one sherd at all sites except for Myrtou-Pigadhes, where the one vessel analysed contained no residues of archaeological significance. Of the non-RLWm ware sherds, two (Kalavassos 9 and Boğazköy 39) yielded fat alone, the residue from Boğazköy on the interior and that from Kalavassos on both surfaces.

### 3.2. Bitumen

Six RLWm ware samples yielded a series of *n*-alkanes with no odd over even preference, together with a series of hopanes and steranes, which are indicative of the presence of archaeological bitumen (Fig. 4) (Connan, 1999; Connan et al., 1992; Peters et al., 2005). All the

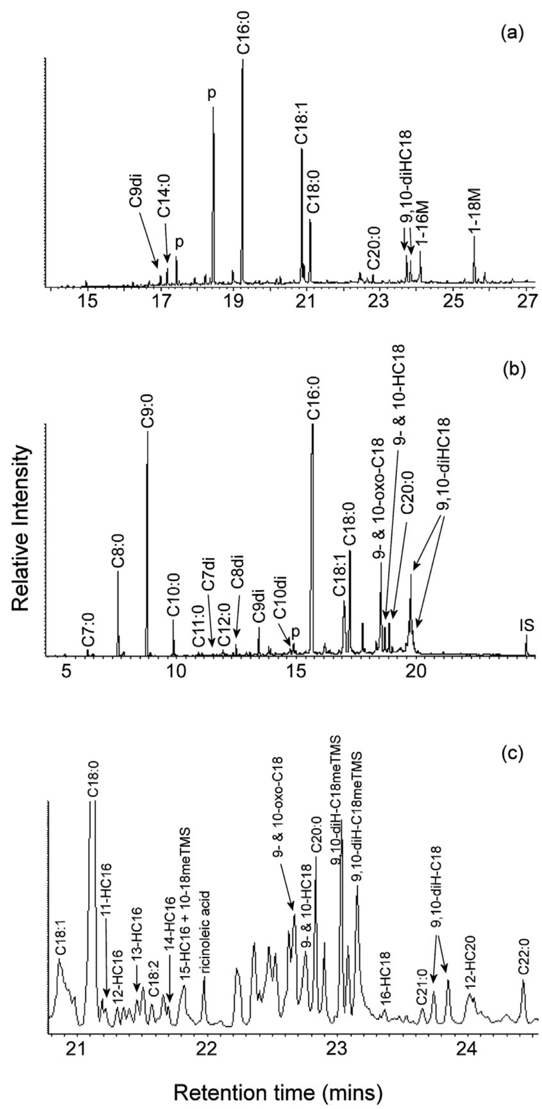


**Fig. 3.** (a) Total lipid extract (TLE of the absorbed residue from the interior of Hala Sultan Tekke sherd 11 between 5 and 25 min retention time; (b) TLE of the residue from Saqqara sherd 2 between 15 and 20 min retention time showing a typical series of short-chain mono-acids and diacids; (c) saponified visible residue from Royal Ontario Museum vessel between 20 and 25 min showing hydroxy- and dihydroxy acids and ricinoleic acid. *x*, number of carbon atoms in molecule; $C_{x:y}$, fatty acid with *x* carbon atoms and *y* double bonds; C*x*di, diacid; *y*-HC*x*, hydroxy fatty acid, hydroxyl group at carbon *y*; *y,z*-diHC*x*dihydroxy fatty acid, hydroxyl groups at carbon *y* and *z*; 1-*x*M, 1-monoacylglycerol; p, phthalate; IS, internal standard.

examples of bituminous residues were from Cypriot sites (Arpera sherd 6, Kalavassos sherds 3 and 4, and Kazaphani sherds 2, 3 and 4); two were interior only (Kalavassos sherd 4 and Arpera sherd 6), one exterior only (Kalavassos sherd 3) and three had evidence of bitumen on both surfaces (Kazaphani sherds 2, 3 and 4). Bitumen was used in antiquity for waterproofing boats, as glue, for decorating ceramics and in medicines (Pollard et al., 2007; Serpico and White, 2000c; Stern et al., 2008a). It is possible that the exterior occurrences represented some kind of decoration but, given the relative concentrations where interior and exterior residues were present, it seems more likely that this bitumen was related to the contents of the vessel. It could have been part of a medicinal treatment or a waterproofing agent used to decrease the porosity of the unglazed ceramic prior to use. It seems unlikely it formed part of the contents if these were not medicinal due to the unpleasant smell.

There are no natural sources of bitumen on Cyprus, and bitumen residues were only found on vessels from Cypriot sites, so the discovery of bitumen in these samples raises the question of where it originated. It was not possible to assign a location for the bitumen using biomarker evidence. None of the samples yielded gammacerane which could potentially rule out a source in the Dead Sea area as samples from that area typically contain large concentrations of gammacerane and tricyclic terpanes (Connan and Nissenbaum, 2004; Nissenbaum and Goldberg, 1980). The composition of steranes, which is also used to discriminate bitumens, crude oils and oil seeps from different source rocks in the near East (Connan, 1999; Connan et al., 2005; Connan and Nissenbaum, 2004), could not be used to determine a source for these samples. In three samples steranes could not be identified at all, while in the remaining samples the steranes often presented as overlapping peaks which did not allow quantification of individual steranes. The Ts (18α-22,29,30-trisnorneohopane) to Tm (17α—22,29,30-trisnorhopane) ratio is also used to distinguish sources of bituminous materials (Peters et al., 2005) but these compounds could only be identified in two of the six residues.

Bulk isotopic analysis of carbon and hydrogen in the interior and exterior residues from Kazaphani sherd 3 placed it within the range of samples from the area of Ras Shamra, Syria, the site of the LBA trade centre of Ugarit (Connan and Deschesne, 1996; Knappett et al., 2005). As trade connections between Cyprus and Ugarit in this period are well attested, this is not surprising (Knapp, 1991). However, if RLWm ware was manufactured, and the vessels filled, on Cyprus for export around the eastern Mediterranean, how did the bitumen get into the vessels? Was bitumen imported into Cyprus for the manufacture of a product to fill RLWm ware vessels? Alternatively, were the vessels exported to Syria, then either treated with bitumen to make them more waterproof or filled with a product containing bitumen, and exported back to Cyprus? On the basis of the data available it is not possible to determine which possibility is most likely, but the evidence does indicate the movement of bitumen across the eastern Mediterranean during this period and the existence of trading links between Ras Shamra/Ugarit and Cyprus. Whatever steps were involved in bitumen or a bituminous mixture being stored or traded in RLWm ware vessels, it seems to have been unique to Cyprus, although the numbers involved are not statistically significant.

### *3.3. Beeswax*

Beeswax was used in antiquity as a sealing agent, adhesive and illuminant, in medicines and cosmetics, in lost wax casting of metals, in painting and modelling, as part of the mummification process, and as a reuseable writing medium (Crane, 1983; Evershed et al., 1997; Regert et al., 2001; Regert and Rolando, 2002; Serpico and White, 2000b). Sixteen of the RLWm ware sherds yielded residues containing wax esters, hydroxy wax esters, odd-carbon numbered *n*-alkanes and even-carbon numbered long-chain alcohols together with a $C_{16:0}$ fatty acid, which are typical of degraded beeswax (Evershed et al., 2003; Heron et al., 1994; Regert et al., 2001) (Fig. 5 and Table 2). Fifteen came from Hittite sites in Turkey (Boğazköy sherds 2–7, 13, 15, 17, 19, 21, 23, 26 and 30, and Kuşakli sherd 3) and one from the Cypriot site of Kouklia (sherd 1). In 13 sherds the beeswax residues were present only or mostly on the interior surfaces (Boğazköy sherds 3–7, 13, 15, 17, 23, 26 and 30, Kuşakli sherd 3, and Kouklia sherd 1), while the other residues were present either on both surfaces (Boğazköy sherds 19 and 21) or only on the exterior (Boğazköy sherd 2). The exterior residues may have been the result of spillage of the contents down the exterior surfaces of the vessel when filling or dispensing the contents, or seepage through the vessel wall from the high concentrations of beeswax on the interiors (typically between 50 and 500 μg/g), as observed for fats by Stern et al. (2000). In addition, in the one case where all the wax was on the exterior surface, this could have been applied deliberately to the exterior of the vessel.

In all but two cases, the samples also yielded traces of $C_{18:0}$. This is not generally considered to be present in beeswax but fresh beeswax

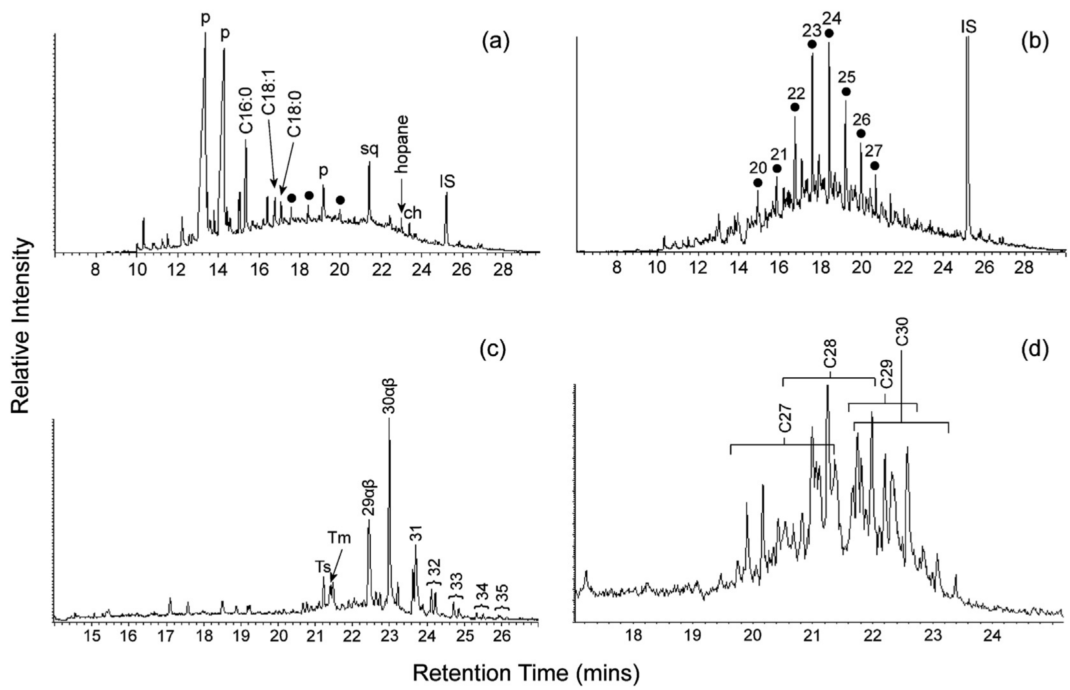


**Fig. 4.** The residue from the interior surface of Hala Sultan Tekke sherd 3. (a) Total ion chromatogram; (b) ion extraction for *m/z* 85 showing *n*-alkanes; (c) ion extraction for *m/z* 191 showing hopanes; (d) ion extraction for *m/z* 217 showing sterane distribution. *x*, number of carbon atoms; $C_{x:y}$, fatty acid with *y* double bonds; ● *x*, *n*-alkane with *x* carbon atoms; p, phthalate; sq., squalene; ch, cholesterol; IS, internal standard; Ts, 18α-22,29,30-trisnorneohopane; Tm, 17α-22,29,30-trisnorhopane. Configuration is shown for the hopanes if known; steranes are shown as ranges as the individual steranes coelute such that one peak may comprise two or three sterane isomers.

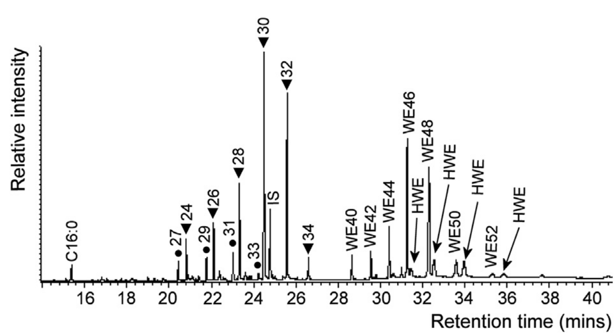


**Fig. 5.** Total ion chromatogram of the residue from the interior of Boğazköy sherd 6, between 15 and 40 min retention time. *x*, number of carbon atoms; $C_{x:y}$, fatty acid with *y* double bonds; ● *x*, *n*-alkane; ▼ *x*, *n*-alcoholWEx, wax ester; HWE, hydroxy wax ester; IS, internal standard.

does contain stearic acid esters not generally seen in GC–MS analyses due to their high molecular weights (Asperger et al., 1999, 2001; Bonaduce and Colombini, 2004; Garnier et al., 2002; Jiménez et al., 2003; Regert et al., 2001; Tulloch, 1971; Tulloch and Hoffman, 1972). Neither of the fresh, modern beeswax samples prepared by solvent extraction yielded $C_{18:0}$, although small amounts of $C_{16:0}$ were present, but this was expected as fatty acids are released from the wax esters by hydrolysis during degradation (Regert et al., 2001). Both samples of modern beeswax yielded low levels of $C_{18:0}$ after saponification.

The majority of the vessels were definitely (five) or tentatively (six) identified as spindle bottles, with two possible arm-shaped vessels, one arm/spindle, one unknown and one lentoid flask/spindle bottle (see Table 2) (Knappett et al., 2005; Mielke, 2006). It is difficult to see how beeswax could have been stored in spindle bottles, arm-shaped vessels or lentoid flasks because of the long, narrow shape and very small openings. This leaves the possibility that it was used as a waterproofing or sealing agent for the unglazed ceramic, probably applied as a post-firing treatment (Rice, 2005). Beeswax could also have formed part of a mixture with a liquid, fatty material, any other components of the mixture being lost as a result of degradation and dissolution during burial. The other possible explanation for the presence of beeswax, that it was present in honey stored in the vessels, also seems unlikely. Honey is rarely identified directly in archaeological residues as it consists mainly of sugars, which are very soluble in water and generally do not survive over archaeological time. There is little evidence relating to the processing of honey during the LBA in either Turkey or Cyprus, so it is hard to determine whether a significant amount of wax would still be present in it. However, separating the wax from honey is not a complex process and good separation can easily be achieved with basic equipment. The main factor militating against the storage of honey in these vessels is the rapid solidification of honey as it ages, particularly in cold temperatures such as those experienced at Boğazköy during the winter months (see above). This would have made retrieving any honey stored through the very narrow necks of spindle bottles or lentoid flasks, or even through the narrow opening at the 'hand' end of the arm-shaped vessels, almost impossible.

It is interesting to note that six of the local sherds from Boğazköy (Turkey) also yielded beeswax (all from the interior) and only one example of beeswax alone was found in any other area (Kouklia, Cyprus). This is a very specific association between the area where the vessels were used and the contents or treatment of those vessels. It also raises the question of whether the beeswax originated in Cyprus or in Turkey. Were the vessels exported from Cyprus already containing the beeswax, were the empty vessels exported for treatment or filling in Turkey, or were they reused in Turkey? The presence of beeswax in local vessels of similar shapes certainly suggests that the presence of beeswax is related to a specific use of the vessels or their contents in the context of Hittite sites in Turkey.

### 3.4. Resin

Three sherds of RLWm ware yielded residues containing pimaric and dehydroabietic acids ((Hala Sultan Tekke 2, 5 and 6) with Hala Sultan Tekke 6, exterior, also yielding sandaracopimaric and 7-oxo-dehydroabietic acid. (Fig. 6). Pimaric acid is present in fresh *Pinaceae* spp. resin, and the other compounds are degradation products of these

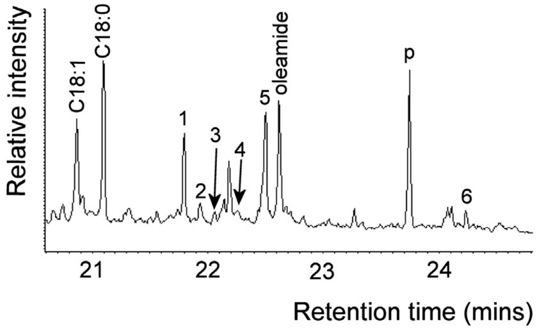


**Fig. 6.** Total ion chromatogram of the residue from the exterior of Hala Sultan Tekke sherd 6 between 20 and 25 min retention time, showing compounds characteristic of *Pinaceae* spp. resins. $C_{x:y}$, fatty acid with *x* carbon atoms and *y* double bonds; 1, pimaric acid; 2, sandaracopimaric acid; 3, abietic acid; 4, didehydroabietic acid; 5, dehydroabietic acid; 6, 7-oxo-dehydroabietic acid; p, phthalate. The oleamide present is probably part of the contamination with plastic, indicated by the presence of large abundances of phthalates as alkylamides are used as slip agents in the manufacture of plastics.

resins (Colombini et al., 2003, 2005; Peters et al., 2005; Pollard and Heron, 2008). Although dehydroabietic acid can be found in rivers (Dsikowitzky et al., 2004) and is also used in some plastics (Voedsel en Waren Autoriteit, 2005) and other packaging (Mitani et al., 2007), no mention can be found of pimaric acid, sandaracopimaric acid or 7-oxo-dehydroabietic acid in these contexts. In addition, the resinous residues are only present on one surface of each sherd, making it unlikely that these compounds are contaminants.

*Pinaceae* spp. resins have been identified in mummified material, adhesives, scented products and as a waterproofing, sealant or post-firing treatment for ceramic vessels (Colombini et al., 2000; Evershed et al., 2001; Manniche, 1999; Regert, 2004; Serpico and White, 2000c). It is again unlikely that resin would have been stored in these vessels, so either the resin was used as a waterproofing agent for the surface of the ceramic or was part of a mixed commodity, the other components of which have disappeared. A mixture of resin and plant oil, for example, might have been used as a scented product. However, it is not possible to distinguish between these scenarios on the basis of the GC–MS evidence.

### 3.5. Mixed residues

All the mixed residues consisted of one of the three non-fatty materials (beeswax, bitumen and *Pinaceae* spp. resin) combined with the fatty material, probably plant oil, as described above. Seven RLWm ware sherds, from Boğazköy (sherds 16, 24, 28 and 29), Kuşakli (sherds 1 and 2) and Kouklia (sherd 4), yielded mixed oil/fat and beeswax residues. Degraded beeswax does contain fatty acids, but these generally only include significant amounts of $C_{16:0}$, $C_{24:0}$ and long-chain hydroxy fatty acids (Ribechini et al., 2009), which are the most abundant fatty acids in fresh beeswax (Jiménez et al., 2003). Therefore, to identify a mixture of fatty material and beeswax, significant abundances of $C_{18:0}$ (similar to $C_{16:0}$) and possibly $C_{18:1}$ need to be present: which was the case in all seven samples. In three of these, short-chain acids (down to $C_{7:0}$) were present and in two of those residues diacids $C_{6:0}$–$C_{12:0}$ were also present. These fatty acids are not present in beeswax but are typical of degraded, unsaturated fats or oils (Copley et al., 2005d; Evershed et al., 1997; Heron et al., 1994; Regert et al., 1998, 2001). Of the non-RLWm ware sherds only one (Boğazköy sherd 37) yielded a mixed fat and beeswax residue.

Five sherds of RLWm ware yielded residues containing a mixture of bitumen and oil/fat, all from Cypriot sites (Arpera sherds 2 and 7, and Hala Sultan Tekke sherds 3, 4, and 9). Bitumen and the fatty material were found on interior surfaces in all but one case (Arpera 2), where the bitumen was present on both surfaces but the fat only on the interior surface. There was only one example of fat and resin present in the same vessel (Kuşakli sherd 4), which was not RLWm ware but a spindle bottle form in a local, brown, polished fabric.

All the mixed residues raise the same questions about the contents of the vessels. Do the residues represent a mixture, more than one use, or a post-firing treatment, waterproofing or sealant and contents? In all cases the fat is probably a plant oil, for the reasons discussed above, but the second component would be solid, or at least very viscous, at normal room temperature. This makes it unlikely that beeswax, bitumen or resin would have been stored in the vessels, except in the case of Hala Sultan Tekke sherd 3, which could be a bowl (see Table 1). This does not exclude reuse of the vessels, but does exclude use for the storage of bitumen, beeswax or resin alone as one of the uses. It is not possible to tell from the GC–MS evidence whether the identified materials represent a waterproofing agent and contents or a mixture. It should also be noted that the contents of the vessels may also have contained other materials that have not survived over archaeological time.

### 3.6. GC-C-IRMS analysis

The results for modern plant oils already published cluster in the area between the accepted values for ruminant and non-ruminant adipose fats, if the accepted values for UK fats are used (Copley et al., 2005a, 2005b, 2005c; Evershed, 2008b; Mukherjee et al., 2008). This was a surprising result, as all the isotopic signatures for oils, with the exception of moringa oil, formed a very tight cluster. If the isotopic values of ruminant, dairy and porcine fats are extended to include values from the eastern Mediterranean (Dunne et al., 2012; Gregg et al., 2009; Romanus et al., 2007), there is also a degree of overlap with porcine fats.

The modern beeswax samples exhibit $\delta^{13}C_{18:0}$ values similar to the oils but enriched $\delta^{13}C_{16:0}$ values. It should be noted that the modern beeswax was from unspecified geographical areas and only represented by two samples, allowing no assessment of the variability of isotopic values in fresh comb wax from the eastern Mediterranean. Interestingly the second sample of beeswax was contaminated with high levels of a homologous series of *n*-alkanes with no odd over even preference. This indicates that paraffin wax was used during the management of the hive (s) and has been incorporated into the comb wax. However, the alkanes did not appear to have influenced the isotopic signatures of the fatty acids, as the modern samples plotted very close to each other.

The archaeological residues that GC–MS analysis identified as containing only fatty material, the three visible residues (one from Saqqara and the two museum samples from Egypt and Cyprus) and the absorbed residue from Kouklia sherd 6, showed isotopic signatures in the same range as the modern plant oils (Fig. 7). The two residues from Kilise Tepe (from sherds 205 and 206) and that from Saqqara sherd 2 were similar in signature but slightly enriched in $\delta^{13}C_{16:0}$ compared with the modern plant oils. As stated above, the modern plant oils are isotopically similar to a mixture of ruminant and non-ruminant adipose fats, so it is possible (from the isotopic results) to conclude that the contents of these vessels could be a mixture of animal fats. However, although small amounts could be present, the shape of the vessels excludes the possibility that they contained large amounts of animal fats. The isotopic results for the residue from the interior of Boğazköy sherd 1 were different and outside many of the accepted ranges for terrestrial fats. These residues potentially lie in the range of marine fats or oils but, given that this particular sample was taken from the inside of the sherd and the main fat residue was actually on the exterior, it is more likely that they represent contamination.

Isotopically, the residue considered to be beeswax (Boğazköy sherd 21) plotted relatively close to the two modern raw beeswax samples, although slightly more negative in $\delta^{13}C_{18:0}$ (Fig. 7). The isotopic values of this archaeological sample do not match any accepted ranges for fatty materials although they show an offset between $\delta^{13}C_{18:0}$ and $\delta^{13}C_{16:0}$ > 3.3‰. This is generally considered to be indicative of milk,

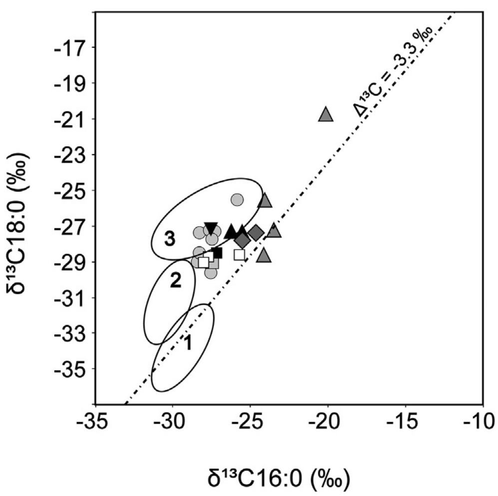


**Fig. 7.** Stable isotope results of archaeological samples and modern plant oils. Ellipses represent the ranges of dairy fats (1), ruminant adipose fats (2) and porcine fats (3) based on the accepted ranges for the UK (Copley et al., 2005a–c; Evershed, 2008b; Mukherjee et al., 2008) augmented by values from eastern Mediterranean and Turkish samples (Dunne et al., 2012; Gregg et al., 2009; Romanus et al., 2007). All archaeological samples were corrected for the addition of modern carbon during derivatisation and modern oil samples were corrected for post-industrial changes in atmospheric values of $\delta^{13}C$. ●, modern plant oils; ◆, modern raw beeswax; ▲, Boğazköy sherds 1, 21, 28 and 29; ▲, Kilise Tepe sherds 205 and 206; ▼, Kouklia sherd 6; □, Saqqara sherd 2 and visible residue (two samples); ■, Royal Ontario Museum visible residue; ■, Medelhavsmuseet visible residue.

but the values for this sample lie outside the generally accepted range for ruminant milk, as shown in Fig. 7. The presence of milk cannot be entirely ruled out as it is a liquid and was used in the LBA eastern Mediterranean. However, milk is a very perishable commodity and it is unlikely that liquid milk, or a product based on liquid milk, was stored for long periods or traded across large areas of the eastern Mediterranean. The rather inconclusive match with beeswax may be due to the relatively low abundances of $C_{18:0}$ in the sample, which made it less than ideal for accurate acquisition of an isotopic value.

The two mixed fat and beeswax residues (from Boğazköy sherds 28 and 29) sent for compound-specific stable isotope analysis plotted closer to the modern raw beeswax than to the fat or oil samples (Fig. 7). The $\delta^{13}C_{16:0}$ values were significantly enriched with respect to the oils, as to a lesser extent were $\delta^{13}C_{16:0}$ values for modern beeswaxes, while the $\delta^{13}C_{18:0}$ values were similar to those of the oils: unsurprising, as most of the $C_{18:0}$ in a mixture of beeswax and oil would come from the oil. It is hard to draw any conclusions from these particular results except that the fatty acids do not appear to come from plant oils alone and may represent a mixture from different sources, including beeswax, as shown by the GC–MS analysis.

### 3.7. HPLC-MS-MS analysis

Tartaric acid was not identified in any of the 17 samples analysed by HPLC-MS-MS. This result fails to show the presence of wine in any of these 17 vessels from four different sites on Cyprus and in Turkey. This is a relatively small sample size so it is not possible to say definitively that wine was never stored in any RLWm vessels but it now seems less probable that the storage of wine or a wine-based commodity was the main use.

### 3.8. Vessel volume calculations

The approximate vessel volumes for the six spindle bottles were calculated as between 0.27 and 3.1 l with a mean of 0.84 l. For the two lentoid flasks the volumes were calculated as 0.24 and 0.28 l, in contrast to the measured volume of a very large lentoid flask from Kalavassos of 5.5 l (South and Steel, 2007). Arm-shaped vessels group into two distinct forms, long- and short-form, the long-form being much more abundant in the archaeological record. Two long-forms and one short-form were identified for the volume calculations and the respective volumes were 0.81, 0.57 and 0.33 l.

Although this was not a comprehensive exercise, it did provide an estimate of the range of sizes available in each form, and there was no reason to assume that these vessels were not typical. In general, the volumes were below 1 l, with only occasional outliers with volumes of a few litres. This contrasts with the bulk storage of olive oil at sites like Building X at Kalavassos, which involved large pithoi with volumes between 600 and 1000 l (Tsipopoulou and South, 2012; A.K. South, personal communication), and Mediterranean transport, which was most frequently in amphorae with volumes of approximately 7–27 l, for example Canaanite amphorae (Pulak, 1997; Serpico et al., 2003).

RLWm ware vessels are generally smaller than the ubiquitous Canaanite amphorae and this, combined with their frequent occurrence in funerary or temple contexts, indicates that the contents probably had added value. The RLWm ware vessels yielded four materials: a fat (probably plant oil, including four positive identifications of castor oil), beeswax, bitumen and *Pinaceae* spp. resin. The fat was the most common residue, and in mixed residues the mixture always comprised the fat/oil and one of the other materials. The residues indicated an oil-based commodity or commodities containing a proportion of castor oil in at least some cases. If the beeswax, bitumen and resin were not different forms of sealing the unglazed vessels, the contents may also have contained these materials, although never more than one at a time, perhaps a hint of several separate commodities. These could have been medicinal, suggested by the castor oil and/or bitumen; a scented oil with pine resin as part of the aromatic component; a flavouring (unlikely in the presence of castor oil, beeswax or bitumen); or a cosmetic preparation. Several commodities could have been traded in these vessels, maybe with the different shapes containing different products, although this cannot be proved from the evidence available. The vessels that yielded no residues may have contained other commodities that have not survived over archaeological time, such as water-based liquids. The failure to find any evidence of wine residues cannot be taken as definitive, as this could be related to the survival of wine residues at the individual sites, the sample selection or the small size of the sample.

### 3.9. Variation and similarity in the contents of RLWm ware and its place within trade across the LBA eastern Mediterranean

The first, and most basic, observation that can be made from these results is that RLWm ware vessels did not always contain the same commodity. The majority of the residues were an oil-based product but it appears that this was not always the same product. In some cases castor oil was present, in others bitumen, beeswax or pine resin was part of the contents. This indicates that the ware itself cannot have been associated with one particular commodity, even if those commodities were all based on a plant oil or oils. The fact that at least a few samples of each type of residue came from Cyprus may support the theory that the ware was made on and exported from Cyprus (although see the discussion on beeswax below).

Exactly what the contents of these vessels were used for is not easy to determine. A common theory has been that scented oils were the possible commodities (Eriksson, 1993; Mielke, 2007), and Eriksson (1993) took the occurrence of RLWm ware vessels in the graves of women and children on Cyprus and in Egypt and the Levant as supporting this idea. However, some of the residues contained castor oil or bitumen, which would not be used in scented oils because of their strong odour and seem more medicinal than cosmetic. Others contained pine resin, which might be used to create a scented oil. The majority of the fatty residues yielded no other ingredients apart from the oil, which provides no evidence of the product in these vessels beyond the fact that it was based on a plant oil. This is not surprising, as molecules that give plants their perfume are by nature very volatile; it is these that we detect as vapour when we smell something. In many scent-producing plants their unique chemical signatures are these small, volatile molecules, which are lost by evaporation over archaeological time. Resinous exudations are different, as they produce not only the small, volatile molecules but much larger terpenoid compounds that are resistant to degradation and that have to be released by burning or heating. The use of RLWm ware vessels in Turkey is probably different as burial practices in Hittite culture did not leave graves containing grave goods, and RLWm ware vessels are found in temple and domestic contexts.

The lack of sufficient dating evidence for many of the samples precludes any conclusions on whether the contents of the vessels varied over time. It is also difficult to see any correlation between the context in which the vessels were found and the contents. In addition, there is no significant correlation between the shape of the vessel and the contents. There were very few examples of lentoid flasks (16) and arm-shaped vessels (only eight tentative identifications). There were several miscellaneous shapes such as bowls and juglets (eight) and 22 sherds from unidentified forms, making any statistical analysis on the basis of shape almost impossible. However, it is interesting, although not statistically significant, that six of the 11 residues consisting partly or wholly of bitumen came from lentoid flasks, and of the five that did not two were from sherds where the original form of the vessel was not clear.

The main variation in the contents of the vessels was with geographical area of the finds, in other words the location where the vessel was last used (Fig. 8). Despite the variation in preservation at individual sites, this geographical association was still apparent. For example, only two residues from Cyprus yielded beeswax whereas many yielded fatty material. In contrast, many sherds from Turkey yielded beeswax, some in combination with fatty material, and few yielded fatty material alone. In general beeswax is more resistant to degradation processes

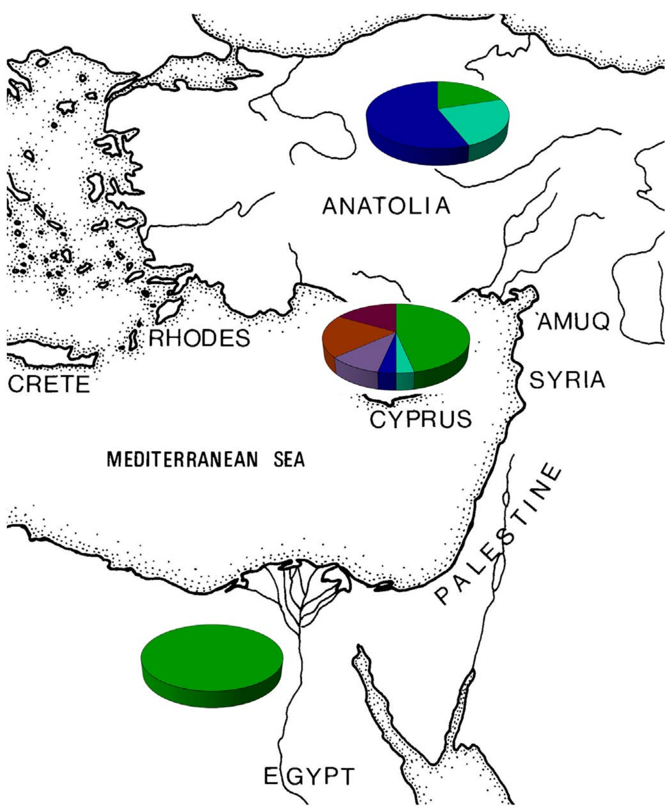


**Fig. 8.** Map with pie charts showing the percentage of each residue present in each geographical region where more than one vessel was sampled. ■, fat/oil; ■, beeswax; ■, beeswax and fat mixed; ■, *Pinaceae* spp. resin; ■, bitumen; ■, bitumen and fat mixed.

than fatty material, as it is solid at most room temperatures, very insoluble in water and contains many unreactive compounds such as alkanes (Eglinton and Logan, 1991). In this case it would be expected that, if beeswax was always a component of RLWm ware residues, it would survive preferentially in Cyprus and Egypt, as it does in Turkey, producing more residues where beeswax remains and the fatty material has disappeared. This was not the case. It therefore seems probable that the vessels going to Hittite sites in Turkey were being used or reused in a different way compared with RLWm ware vessels exported to other areas.

Similarly, although the number of residues containing bitumen was small, they were all from Cypriot sites, while the bitumen itself was probably from the area around Ras Shamra/Ugarit in Syria. In this case it may have been the bitumen itself that was imported into Cyprus from Syria for use in RLWm ware vessels. The number of samples containing pine resin was even smaller and, while three samples were from the single site of Hala Sultan Tekke on Cyprus, the fourth was from a non-RLWm ware spindle bottle from Kuşakli in Turkey. From these numbers it is not possible to say anything significant about the distribution of any commodity containing resin.

RLWm ware is a small but ubiquitous part of the extensive trade and exchange of goods taking place in the eastern Mediterranean and beyond during the LBA. Documentary, pictorial and archaeological evidence, including the excavation of LBA shipwrecks such as the Ulu Burun, have provided evidence of the scale of this trade and exchange (Bass, 1991; Cline, 1994; Haldane, 1993; Knapp, 1991; Pulak, 1997). The goods involved included bulk commodities such as grain, tin, copper, olive oil and wine, but also many items that were not basic essentials, many being rare or expensive luxuries. These included raw materials such as ivory, ostrich eggs, semi-precious stones, honey, resin, herbs, fruit, spices, honey, olives, nuts, minerals, gold, silver and salt; manufactured items such as leather goods, textiles, scented oils, dyes, glass, furniture, vessels of stone, ceramic and metal (and in some cases their contents), jewellery and other items made of precious metals; horses;and slaves (Bass, 1991; Bourriau et al., 2001; Cadogan, 1993; Cline, 1994; Eriksson, 2001; Fletcher, 1998; Haldane, 1993; Hankey, 1993b, 1993a; Karageorghis, 2002; Knapp, 1991; Manniche, 1999; Merrillees, 1968; Mielke, 2007; Negbi and Negbi, 1993; Palmer, 2003; Serpico and White, 2000a; Shelmerdine, 1985; Todd, 2001; Yon, 2003). Goods from further afield were also traded across the eastern Mediterranean, including amber from the Baltic and ebony from tropical Africa (Knapp, 1991; Pulak, 1997). There is also some evidence for the exchange of skills and services via the movement of specialists such as doctors, scribes, diviners, artists and other skilled craftsmen between the Hittite, Egyptian, Aegean, Ugaritic and Babylonian courts (Bryce, 2002; Cline, 1994).

The mechanisms by which these goods moved about the LBA eastern Mediterranean are not always entirely clear. There is documentary evidence for gift exchange between the rulers of sovereign states and the payment of extensive royal dowries (Bryce, 2002; Cline, 1994; Karageorghis, 2002; Knapp, 1991). Both Egyptians and Hittites claimed tribute from vassal states in the Levant and elsewhere, possibly including Cyprus (Bryan, 2000; Bryce, 2002; Karageorghis, 1982), with the vassal states often expecting a degree of protection from external threats, protection for their merchants and basic supplies in times of famine in return for their loyalty (Karageorghis, 2002; Knapp, 1991; Yon, 2003). Trade in the traditional sense of an exchange of goods also took place, mediated by merchants both state sponsored and independent (Cline, 1994; Knapp, 1991; Yon, 2003). It is clear that some trade at least was driven by market forces, for example the fashion for imported Aegean pottery among the wealthy inhabitants of Cyprus during the Late Cypriot (LC) II period (Cline, 1994; Karageorghis, 2002; Knapp, 1991; Yon, 2003).

As RLWm ware is found over such a wide area of the eastern Mediterranean it must have formed part of this trade network, although it is not possible to determine what mechanisms were involved in its exchange. The distribution of the ware shows some very distinctive features that indicate political factors influenced, at least to some extent, where this ware was traded and with whom. For example, the ware disappears from Egypt after 1400 BCE and this has been linked with a changing balance of power between Egypt and the Hittite Empire at this time (Eriksson, 1993). If Cyprus is to be equated with the land of Alishaya mentioned in Hittite records, although this is a disputed interpretation (Artzy et al., 1976; Goren et al., 2003; Goren et al., 2004), then the Hittite king Tudhaliyas I actually claimed Cyprus as part of his sphere of influence about 1400 BCE, and it was used as a place of exile for undesirables banished from the Hittite court during the 14th and 13th centuries BC (Todd, 2001). The later king Šuppiluliuma II claimed to have defeated an Alishayan fleet, landed in Alashiya, defeated his enemies and taken tribute back to his capital at Hattuşa (Boğazköy) in central Turkey (Todd, 2001). There is, however, little evidence for any occupation of Cyprus, or even a significant amount of trade between the Hittites and Cyprus (Eriksson, 2007; Karageorghis, 1982, 2002). Almost no Hittite artefacts are found in Cyprus and RLWm ware is the only Cypriot ware found in any significant abundance at Hittite sites (Kozal, 2003, 2007; Todd, 2001). Also of interest is the fact that almost no RLWm ware is found on sites in western Turkey, which were in the Minoan/Mycenaean sphere of influence, and no Mycenaean or Minoan pottery has ever been found over years of extensive excavation at the Hittite capital at Boğazköy (Kozal, 2003, 2007; Todd, 2001). In fact Cline (1994) suggests the Hittites may have exercised a trade embargo against the western Turkish area, which has been equated by some with the region of Ahhiyawa. If this was the case, Cyprus must have exercised a high degree of independence, despite Hittite claims, as they imported Mycenaean ceramics in large amounts (Karageorghis, 2002).

The export of RLWm ware to Boğazköy and other places in the Hittite heartland suggests that it was special or particularly valuable to the Hittites: they valued the ware or its contents enough to import only that ware from Cyprus in significant quantities. As outlined above, RLWm ware has recently been found in much earlier contexts at Hittite sites, indicating that it was exported there for much of the lifetime of the ware, and local imitations (vessels in the same shapes but made in local fabrics) are found contemporaneously with classic RLWm ware vessels at Boğazköy and other sites. This may in fact support the theory that the origins of both spindle bottle and arm-shaped vessel forms lie in Turkey (Manuelli, 2009; Mielke, 2007) rather than in Egypt or on Cyprus itself (Merrillees, 1968). The residues found in the RLWm ware samples from Hittite sites in Turkey support the idea that something very different and unique in terms of trade was taking place between the Cypriot source of the ware and the Hittites. The vessels from Turkey, and two exceptions from Kouklia on Cyprus, are the only ones that contain beeswax. In addition, the local vessels in similar shapes excavated from the same context (the Southern Ponds in the temple district at Boğazköy) yielded residues containing beeswax.

As discussed above, it is unlikely that beeswax could have been stored in RLWm ware vessels because it is solid at normal room temperatures, and spindle bottles or arm-shaped vessels are not suitable containers for a solid commodity. The beeswax was therefore either a post-firing treatment for making the vessels less porous, or part of a mixture with something liquid, in this case probably plant oil as wax will not mix effectively with water or wine. We have no way to determine which of these possibilities is correct and it is also impossible to determine whether the beeswax represents the original contents of the vessels as exported from Cyprus, was added to the empty vessels after their arrival in Hittite territory, or represents a reuse of the vessels locally after the original contents had been used. Given that the local vessels in similar shapes also yielded beeswax, one of the two latter interpretations seems more probable as it is unlikely that the local vessels would have been manufactured in Turkey, exported to Cyprus for post-firing treatment and/or filling, and returned to Turkey for use. For these imitations it is also possible that both the contents and the vessels themselves were produced locally, but if that is the case, why go to the trouble and expense of importing RLWm ware vessels, with or without their contents?

The similar contents of both RLWm ware vessels and their imitations are perhaps indicative of the import of the RLWm ware vessels for the ceramic itself. In any case, arm-shaped vessels are not very practical as storage and transport vessels, as they would have been difficult to seal for the transport of liquids, so may have been traded for their own sake and for a very particular use (Kozal, 2003; Mielke, 2007). It is not possible from the results of this study to determine whether arm-shaped vessels were actually used for the same commodities as spindle bottles, as only one securely identified arm-shaped vessel was among those analysed from Turkish Hittite sites. This did contain beeswax, as did one definitely identified arm-shaped vessel and one possible arm-shaped vessel from Kouklia (sherds 1 and 4), but it is not possible to draw conclusions based on such a small number of vessels. The identification of beeswax in the two vessels from Cyprus possibly provides an argument against the export of empty vessels to Turkey and could support a specialist treatment of the ware for Hittite customers.

Mielke (2007) has suggested a ritual rather than religious use of these vessels, which would account for their occurrence in some domestic contexts in addition to the more frequent finds in cultic contexts. This might be some kind of anointing process that was a regular ritual rather than part of a religious act, and it is tempting to see the find of an arm-shaped vessel inside a bath tub at Kuşakli (Mielke, 2007) as supporting evidence for that, although an isolated find should not be used to generalise interpretations. Mielke (2007) also envisaged a potential link between the two commonly occurring shapes at Hittite sites, with the spindle bottle being used as a container for a commodity or commodities used or dispensed from the arm-shaped vessels. What is clear is that, for several centuries, the use of these vessels was somehow integral to Hittite life and culture, particularly within the Hittite heartland on the Anatolian plateau. The Cypriot potters who exported RLWm ware to Boğazköy and other places must have maintained close connections within Hittite culture, despite the paucity of archaeological evidence to support extensive trade links between these two areas. Some contact must have initiated the first exchange of these vessels and, if the origin of the spindle bottle and arm-shaped forms does indeed lie in Turkey, maybe this was in the form of the movement of people and ideas, with Cypriot potters starting to make these forms and going on to use the emerging RLWm ware fabric to produce a ‘premium’ version of local wares that quickly became an integral part of Hittite cultural practice. These vessels could then have been then adopted as transport vessels for other commodities going to other markets. However, this does not necessarily imply a shared ritual or cultic practice between Cyprus and the Hittites, as has sometimes been claimed (Mielke, 2007).

It has often been suggested that RLWm ware reached the Hittite heartland via trading centres such as Ras Shamra/Ugarit on the Syrian coast, hence via Cilicia and the Cilician Gates to the Anatolian plateau (Kozal, 2003, 2007). However, there is little evidence of the movement of RLWm ware through Cilicia as it is very rare at all sites excavated so far (Knappett et al., 2005; Kozal, 2003, 2007). It is more likely from the distribution of the ware that it was imported directly from Cyprus by sea to the mouth of the Göksu River and up the Göksu Valley, where it is found at sites such as Kilise Tepe (Knappett et al., 2005; Kozal, 2003, 2007; Mielke, 2007). This direct trade would support the idea of a direct connection between Cypriot potters making RLWm ware vessels and their customers on the Anatolian plateau, a connection that appears to be unique as evidence for other trading links between the Hittites and Cyprus is scarce. Of course, there are many other possible scenarios that could explain the archaeological evidence, and new excavations, ceramic evidence and improved agreement on and synchronisation of the various relative dating schemes in use for different geographical areas of the LBA eastern Mediterranean may change the picture significantly.

The other close trading relationship revealed by the contents of

RLWm ware vessels is with Ras Shamra/Ugarit on the Syrian coast. This is not surprising as Ugarit was a centre for trade in the eastern Mediterranean during the LBA, even allowing foreign merchants to set up communities within the city (Cline, 1994; Knapp, 1991; Yon, 2003), and connections between Cyprus and Ugarit are well evidenced (Karageorghis, 2002). The discovery of bitumen from the area of Ugarit in RLWm ware vessels from Cyprus indicates a trade in bitumen as a commodity in its own right. It seems unlikely that RLWm ware vessels, made on Cyprus, would be exported to Syria, have bitumen applied as a post-firing treatment or put into the containers as part of a product made in the area of Ugarit, and shipped back to Cyprus for use. More probably the bitumen had been imported into Cyprus as a raw material or in bulk containers of a commodity containing bitumen and used in the vessels on Cyprus.

## 4. Conclusions

The analysis of residues from 101 sherds of RLWm ware from 13 sites across the eastern Mediterranean has confirmed that organic residues were absorbed and have survived in these very fine ceramics. It has also shown that, for this ware, the condition of the ceramic itself has a greater influence on the preservation of residues than storage in museum collections, the main effect of long-term storage in a museum context being the degree of plastic contamination.

Four commodities, a fat (possibly a plant oil), beeswax, bitumen and *Pinaceae* spp. resin, have been identified in residues from RLWm ware vessels. The most common commodity is the fat or oil, which occurs in all three main forms of the vessels and from all geographical areas. In some cases, castor oil was present as part of the oily residues. The three other commodities were found alone or mixed with fat, but never mixed with each other. It is not possible to determine whether the mixed residues resulted from a mixture contained within the vessels or whether it represents repeated use of the vessels for different commodities or a sealant applied to the interior of the vessels to make them less porous together with the actual contents. An over-riding consideration in the interpretation of these results must be the length and small size of the necks of both spindle bottles and lentoid flasks, which preclude the practical storage of any solid commodity.

The most fundamental conclusion that can be drawn from the results is the fact that the contents of RLWm ware vessels were not always the same and the vessels were used for a variety of products. This disproves the theory that all RLWm ware vessels were used for the same product. It also shows that not all RLWm ware vessels of a particular form were used for the same commodity, in other words spindle bottles did not always contain the same product, which was different to that in lentoid flasks. The occurrence of all types of residue in vessels from Cyprus supports the proposition that RLWm ware was probably made on Cyprus.

The main variation in residues occurred with the geographical area where the sherds were found, in other words at the ‘customer’ end of the trade in the ware. The identification of beeswax only in sherds from Turkish sites, and two residues from Cyprus, indicates either that the Cypriot producers of the ware were producing something very particular for their Turkish customers or the vessels were being used in a very distinctive way at Hittite sites. This may represent a very special relationship between the Cypriot potters producing RLWm ware and the Hittite heartland on the Anatolian plateau and may also support the idea that, in this case at least, the ware was exported for its own sake rather than for the contents. The presence of bitumen from the area of Ras Shamra/Ugarit in Syria in Cypriot vessels indicates the import of bitumen either as a raw material or in a bulk commodity produced in the area of Ugarit.

The study of RLWm ware still raises many questions. Further investigations of both the ceramic and its contents are needed to address these questions, about trade and society in the LBA eastern Mediterranean.

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